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ORIGINAL PAPER

Geographic information system (GIS) application for windthrow mapping and management in Iezer Mountains, Southern Carpathians

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Abstract: Windthrow problem is a difficult task for the forest managers in the Romanian Carpathians and especially in Iezer Mountains. The last windthrow, in July 2005, affected about 370 ha within the study area and left unprotected large slopes with important declivities (20-30°). In our study, we try to propose a tool for forest management, in order to control and minimize the negative effect of wind upon the mountain forest ecosystem. The digital data input derived from forestry data (forest stand typology, age, canopy coverage index, forest productivity class) and from the forest biotope features (soil and topography parameters). The main goal was to find a more objective way for digital layer reclassification in order to obtain the windthrow areas susceptibility map for the Iezer Mountains. Each digital layer has its own weight within the analysis and one of them was difficult to be modeled (the wind features). A statistical approach was developed on the basis of local phenomena and the windthrow features in the Romanian Carpathians. This allowed us to obtain the reclassification conditions for each digital layer. Forest canopy typology and soil features (mainly its volume) were considered as the key factors for the windthrow occurrence analysis. The final windthrow susceptibility map was validated with the help of the statistic occurrence of windthrow areas within each susceptibility class and after a field check of the sites. The result was encouraging, because 92.5% of the windthrow areas fall into the highest windthrow susceptibility class.

Keywords: windthrow; GIS; forest; map; susceptibility

Introduction

Forest has an important ecological task, which can be altered and even lost in the context of the Global Changes (Schröter et al. 2008, EEA 2008). The effects of the recent extreme phenomena like windstorms, drought and fires (Lorz et al. 2010) as well as snow avalanches (Teichl and Bebi 2009) opened new approach directions for the forest managers at regional, and especially, local scales.

The unfavorable environmental factors can affect the functionality of the forest ecosystem, and the windy storms episodes are one of those (Wintle and Lindenmayer 2008). Trees can be usually broken but the most frequent problem is that they can be uprooted, resulting an economical loss. The situation can be critical when large forest areas lying on the slopes are put down by stormy winds in a very short time (Nilsson et al. 2004; Yoshida and Noguchi 2009).

To handle this process, one needs reliable spatial information and a standard for the GIS spatial analysis and modeling of the windthrow phenomenon (He 2008; Seidl et al. 2011). The process gets complicated because of data inconsistencies, which are rarely available in digital form and even in analog format. Different authors apply GIS tools and remote sensing techniques in forest ecology research since the 1990s (Walshe and Ní Dhubhain 1998; Quine and Bell 1998; Peltola et al. 1999; Ruel 2000; Gardiner and Quine 2000; Ruel et al. 2001; Ruel et al. 2002; Wohlgemuth 2002; Cucchi et al. 2005; Zeng et al. 2007; Krejci et al. 2010; Rich et al. 2010).

In the Romanian Carpathians, the windthrow phenomenon has been described since the first half of the 19th century in Bucegi Mountains (Giurgiu 1995). Recent statistics (Dinca 2008, unpublished) shows that about 28% from the Romanian afforested surface is vulnerable to windthrow phenomena.

Forest management specialists and researchers analyzed these issues in the Romanian Eastern Carpathians, where windthrow-induced wood mass loss was higher than the main wood production of some of these canopies-stands (Popescu Zeletin 1951; Dissescu 1953, 1960, 1962; Marcu et al. 1968; Ichim 1976, 1990; Vlad and Petrescu 1977). There is an increasing interest to integrate the computer based modeling (mainly GIS and remote sensing techniques) as an analytical method in forest manage-

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ment (Gancz et al. 2010; Savulescu 2010 unpublished, integrates Landsat imagery with GIS applications).

Forest resource management is a national wide problem. The situation started to be more complex than expected. Wood harvesting continued at dramatic and uncontrolled dimensions in Romanian mountain areas, where forest gaps enlarged and created efficient corridors for wind circulation. They have to be updated every decade and they still are in analog format. A lack of information regarding the ownership structure interrupted their updating process. The windthrow issue is only described within these documents in less realistic frameworks.

Recently the Institute of Forestry Research and Development started to build a complete GIS database for all the afforested parcels in Romania.

The main purpose of our paper is to provide an example of a GIS analysis, which could be a reliable tool for the mapping and management of the areas prone to windthrow. The Iezer Mts. were chosen as a case study area.

Study area

The Iezer Mountains (530 km^2, 2,470 m altitude in Iezerul Mare Peak) are a representative mountain region within the Southern Carpathians, in the Fagaras Mountains Group (Fig. 1), developed mainly on crystalline rocks. The mountain landscape preserves some glacial cirques from the Pleistocene and largely developed planation surfaces and erosion levels at about 1,000−1,200 m, 1,400−1,600 m and 1,800−2,000 m. The region is famous for sheep grazing within old traditional sheepfolds situated close to the timberline (1,400 to 1,800 m) but it is also important for its large afforested surface (411 km^2, 77.5% of the whole area). There are four vegetation zones (Mihai et al. 2007): the deciduous forest zone, between 600−700 m and 1,300−1,400 m), the coniferous forest zone (1,400−1,800 m), the subalpine zone of dwarf pine (1,800−2,250 m) and the alpine pastures zone (2,250−2,462 m).

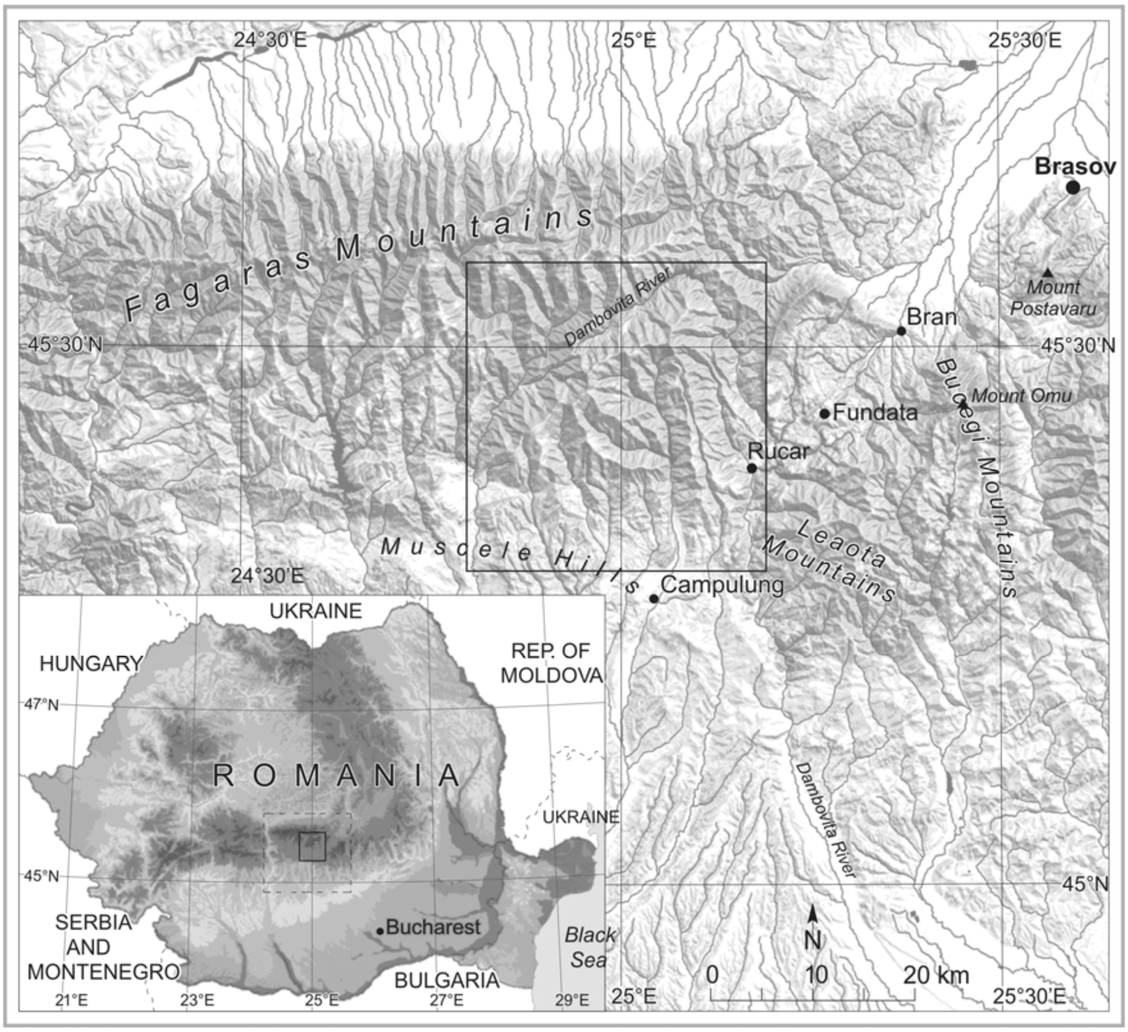

Fig.1 Iezer Mountains position within the Romanian Carpathians.

The Iezer Mountains have a temperate mountain climate. The high mountain climate (above 1,850–1,900 m) is humid and cold; at lower elevations the middle mountain climate extends to around 650–800 m. Air temperatures vary between 7°C and

−2°C above 2,100 m. Generally, the relief accounts for differences between rainfall on the western and northwestern slopes (where it is higher) and on the eastern and southeastern slopes. Along the southern border of these mountains, the average rainfall is 800 mm/year, while at higher elevations it is about 1 200 mm.

Wind regime is characterized by highest speeds on the highest ridges, above the timberline. There is no weather station within the Iezer Mountains, but judging from the neighboring stations datasets (Omu Peak 2,505 m in Bucegi Mountains), the strongest winds blow from north and northwest. They cross the main ridges of the Fagaras and Iezer-Batrana-Papusa mountains and fall on the opposite steep slopes (20−40°) within the Raul Targului and Rausor upper catchments (Fig. 2).

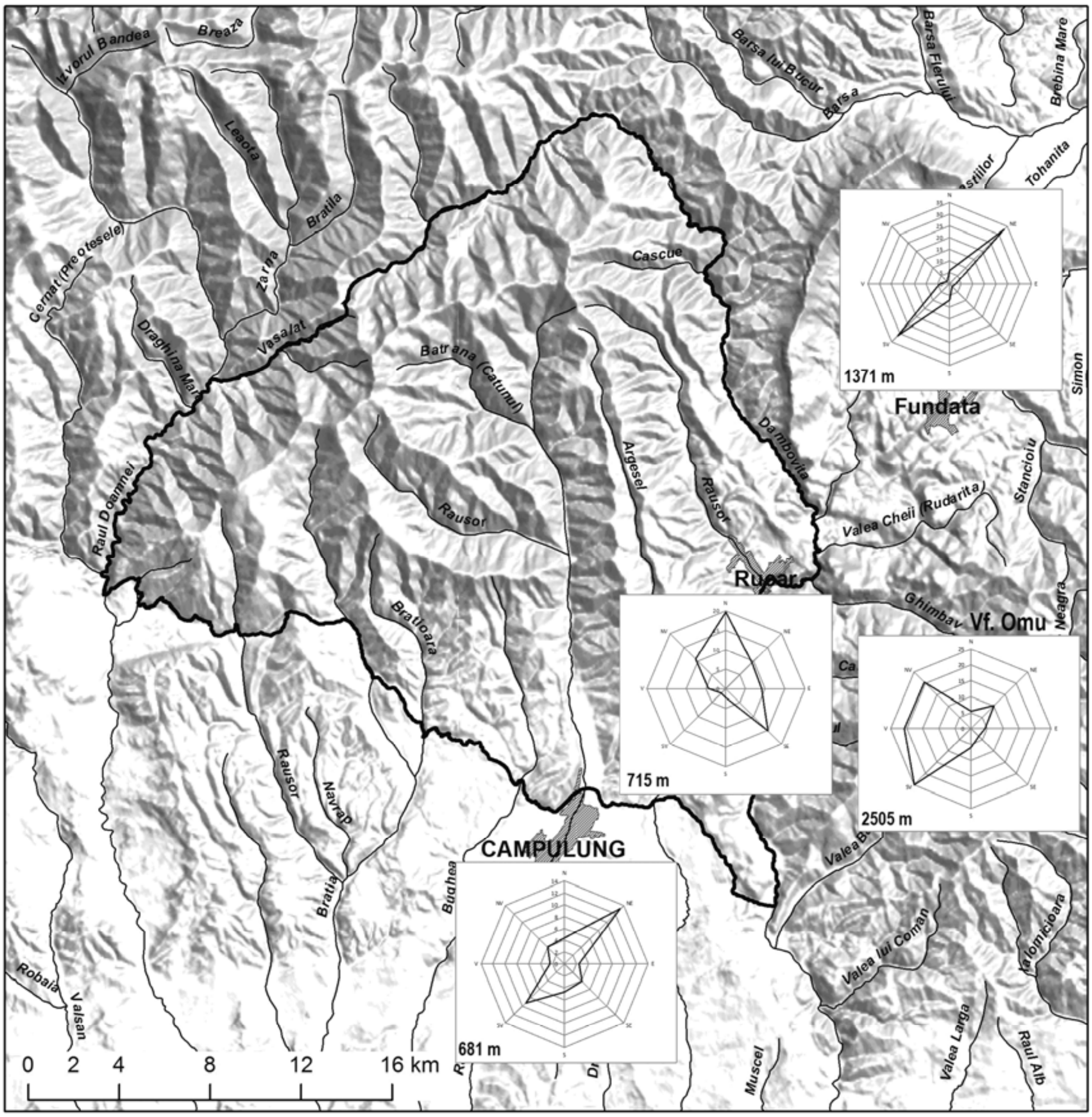

Fig. 2 Wind roses around Iezer Mountains and topographic features. Digital Elevation Model derived from Shuttle Radar Topographic Mission Data. Source: SRTM from Global Land Cover Facility, wind flow direction (%) (1961−2000) from National Meteorological Authority, Bucharest.

The following environmental conditions have influenced the vegetal altitudinal zones in the Iezer Mountains:

(1) The alpine zone higher than 2,200–2,250 m, where meadows occur, associated with *Carex curvula, Festuca supina, Juncus trifidus*, etc.

(2) The subalpine zone between the timberline and 2,000–2,250 m, where dwarf pine (*Pinus mugo*) is associated with juniper (*Juniperus nana*), *Vaccinum myrtillus*, *Vaccinum vitis idaea*, *Nardus stricta, Festuca supina*, etc.

(3) The coniferous forest zone from 1,300–1,400 m to about 1,800 m; in locally favorable climates the timberline extends above 1 , 860 m, whereas on the south-facing slopes these forests develop above the 1,500 m contour line owing to the impact of centuries of grazing. Spruce (*Picea abies*) and silver fir (*Abies*

alba) *are also present*.

(4) The deciduous forest zone lower than 1,300−1,400 m, where beech *(Fagus silvatica*) dominates, together with birch *(Betula pendula*) and hornbeam *(Carpinus betulus*).

Forests in the Iezer Mountains reflect a strong anthropogenic influence. Since 1900, the easiest access area within the Central and Eastern sectors of these mountains was the first timber harvesting areas. The maximum logging intensity took place between 1920−1926 and 1948−1956. Timber was usually harvested after the total deforestation of the mountain slopes. A forest recovery period started in 1932 (till 1945) and another in 1974, within the framework of the two main national reforestations programs (Table 1). Only coniferous species were used for this recovery effort. The forest recovery processes changed the primary biodiversity patterns and created new forest ecosystems having a high degree of vulnerability related to biotic and nonbiotic damaging factors.

Table 1. Timber harvesting potential volume (m^3/year) calculated by the forestry engineers for cadastral purposes (*1*) and the effective harvested timber volume (*2*) within the Productive Units Rausor, Campulung Forestry, Iezer Mountains (1950-1996). Source: the forestry cadastral documentation, ICAS Bucharest. The 4th row represents the increasing factor of timber harvested (1./2.)

Productive Unit	1950−1964		1964−1974		1974−1985		1985−1996	
IV Rausor	1.	2.	1.	2.	1.	2.	1.	2.
	5600	26540	7650	12060	1210	1210	385	503
	4.7		1.6		1.0		1.3	

Materials and methods

Wohlgemuth et al. (2002) proposed a new scheme for forest ecological management, based on the ecological features related to the windthrow potential factors. They can be divided into three groups: (1) Natural endogenous factors like tree species, age, and coverage degree of the canopy and production class; (2) Natural exogenous factors, divided into dynamic factors (wind direction and speed) and local factors (topographic features, soil features, groundwater features); (3) Anthropogenic factors, depending on the forest management features which means the exploitation modes, the forestry road network development and management, the policy of forest regeneration (Firm et al. 2009). This type of factors are reflected into the first category (endogenous factors) through the species used for the reforestation of slopes, the forest regeneration modality etc.

Data sources

Our GIS analysis integrates these categories of factors within a digital model and to obtain a reliable map to be validated and integrated within the future forestry cadastre documentations.

The windthrow susceptibility mapping in the Iezer Mountains started from empirical and observational methods (Mitchell et al. 2001) adapted to a GIS modeling of the phenomenon (Kemp 2008). The result is a digital layer containing the forest patches, which are susceptible to windthrows as a product of the conditioning factor as we stated before.

Each of the factors (Table 2) were mapped in a grid format after the conversion of analogical data into digital data and after quantitative analysis designed for the evaluation of the weight of each layer within the main GIS modeling application (Borrough 2001; Bernhardsen 2001; Goodchild and Longley 2005; Kemp 2008).

The main dataset integration was related to the forestry data. This was collected from the local forestry authorities but only in paper format. These documents include the forestry cadastre and they were updated every ten years starting since the 1960s. Maps were scanned at higher resolution and were geometrically corrected. Errors (ca. 5-7 m) were calculated and we obtained a reasonable topologic model by superposing this data with topographic maps and Landsat satellite imagery.

Digital Elevation Model was derived from contour lines with their attributes in order to obtain a reliable slope aspect map at 10 m of resolution.

Another available dataset was related to remote sensing imagery. This was available at medium resolution (30 m) and it was a good opportunity to validate the forestry data (Landsat ETM+ imagery from Global Land Cover Facility Database, reference date 10.05.2002). This is a useful dataset for the validation of vegetation or forestry data like the type of canopies (Mihai et al. 2007). Image classification of the forest canopies, using the supervised maximum likelihood classification offered good samples to compare with the forestry cadastre maps.

Digital color ortophotos since June 2005 flight at 0.5 resolution were used. The data is in natural colors and it was obtained during the peak vegetation season. A visual interpretation was done, but it was necessary to make field check around the patches affected by windthrow in the past years (2005−2009). Forest regeneration appeared mainly within the areas where soil remained on the slopes. It was possible to check also these patches on the ortophotos but also to receive the confirmation from the local forestry engineers and forestry rangers.

Soil cover data. Soil influences the stability of forest stands on slopes in mountain areas (declivity higher than 20−30˚). A digital database was created also from the existing soil maps of the Arges County Soil and Agrochemistry Office (paper format). The soil names were updated, because they were mapped after the 1980 Romanian Soil Reference System, which was replaced in 2003 by the FAO international soil classification system. The data structure contained polygons of soil units and attributes regarding the soil class and typology as well as the soil depth and the soil edaphic volume. The data were validated during the field

campaigns using also some Global Position System surveying in order to locate the points where soil samples were described.

Table 2. Main features of the spatial data integrated within the GIS modelling of windthrows in Iezer Mountains, Southern Carpathians.

Digital data	Data sources	Data validation sources
Natural Endogenous Factors		
Forest composition (species and associations), parcel reference	Forestry cadastre maps (1:20000) (source ICAS Bucharest)	Landsat ETM+ false colour imagery (10.05.2002), Field researches 2001-2009
Age of forest canopies, parcel reference	Forestry cadastre maps (1:20000) (source ICAS Bucharest)	Landsat ETM+ false colour imagery (2002), Field researches 2001-2009
Coverage index of forest canopies (forest consistency index), parcel reference	Forestry cadastre maps (1:20000) (source ICAS Bucharest)	Landsat ETM+ false colour imagery (2002), Field researches 2001-2009
Forest productivity classes, parcel reference	Forestry cadastre maps (1:20000) (source ICAS Bucharest)	Landsat ETM+ false colour imagery (2002), Field researches 2001-2009
Natural Exogenous Factors - Local Conditions		
Slope aspect	Digital Elevation Model derived from the topographic maps (1:25000)	-
Soil morphologic depth	Romania Soil Map 1:200000 (ICPA Bucharest); Soil maps 1:10000 (OSPA Arges); Field soil survey 2001-2009	Field soil survey 2001-2009, GPS survey of soil sampling points
Soil edaphic volume	Romania Soil Map 1:200000 (ICPA Bucharest); Soil maps 1:10000 (OSPA Arges); Field soil survey 2001-2009	Field soil survey 2001-2009, GPS survey of soil sampling points

Methodology

Our approach to modeling process started from the idea that each individual factor had a different weight for the windthrow susceptibility, according to the geographical weighted regression model (Nakaya 2008). This was based on the statistical analysis of all the windthrow events occurred within the study area since 1960. The period was limited to the reliability of the available information volumes. We consider 1960 as representative in Romanian forestry development, because this year opened the first decade after the most important reforestation programs in the Iezer Mountains and the Romanian Carpathians.

The conditions for grid reclassification were derived also from data about windthrows occurrence in the Romanian Carpathians available in our literature (Dissescu 1962; Marcu et al. 1968; Ichim 1976, 1990; Marcu 1983).

According to the local forestry authorities, eight stages of windthrows were recorded in Iezer Mountains between 1960 and 2005. This information is confirmed by the national forestry statistics (Table 3). Windthrow affected 2.6% of the forests in the study area. The windthrows were documented with spatial and temporal information. Large areas occurred since the 1960s, but the most recent and the biggest event was that on July 19, 2005.

The reclassification conditions were applied on each of the digital layers. The Threshold values were derived from literature and field research. Wind-related damages upon the mountain forests are strongly related to the configuration and size of each of the canopies (Lindemann and Baker 2001). These features were referenced to forest patches, as a mapping unit of the afforested area in the Iezer Mountains.

Vlad and Petrescu (1977) studied the Norway spruce forests (*Picea abies*) in Romania, and they concluded that these are the most affected stands in Romanian Carpathians. They were not those from the timberline area but from the sheltered slopes. This is in fact an adaptation of the forest species to wind storms and a response that reflects the slope aspect interaction with the aeolian conditions of the mountain slopes.

Tabel 3. Winthrow stages in Romania since 1960 (Dissescu 1962, Marcu et. al. 1968; Ichim 1976; Vlad and Petrescu 1977; Ichim 1990)**.**

Year of occurrence	Main wind flow direction	Surface affected (ha)
1960	NE	151.22
1964	SW	175.02
1965	NE	240.37
1974	E	38.85
1977	S	59.73
1985	E	11.63
2002	E	11.40
2005	SW	367.88
TOTAL		1056.10

Spruce fir canopies within the mixed forests (together with beech trees and fir trees) are more vulnerable to wind induced damages than the compact spruce fir canopies of the coniferous zones (primary forest canopies with the highest coverage index). Slope aspects with the highest frequency of windthrow phenomena are the northern, northeastern and northwestern ones.

Wind direction and speed are strongly influenced by the mountain topography features. Forest patches on the large mountain valley slopes along the main wind direction are the most vulnerable to windthrows. Along the tributary or secondary valleys, wind impact is not so important, because the stream follow the main valley. The largest windthrow areas features slopes at the end of each secondary ridge, falling in contact with the main wind stream.

Marcu (1983) observed the role of the orographic configuration for windthrow occurrence. All the mountain ridges crossed by the wind streams amplify the effect of windstorms through the occurrence of the vertical component of the wind streams and of other secondary whirlpools. They affect forest on the lee side slopes.

Wind is a key factor when its speed is higher than 25–35 m/s. Local conditions can help the occurrence of the resonance phenomenon within the forest, which can reach the rhythmic balance of trees during the strongest stormy episodes (Marcu et al. 1968). This factor cannot be simply modeled (Mitchell et al. 2008; Zeng et al. 2009) and we consider our analysis is not aimed at this target.

Soil features have a significant importance. Storms can uproot high trees although the soil volume is important for tree stabilization on the mountain slopes. Rainfall before storms can alter the soil physical conditions. Soil cohesion decreases with moisture rainfall and the trees can be easily uprooted by wind (Chirita 1974).

Forest canopy features strongly control the resistance of forest stands against wind damage. Tree species typology, the canopy coverage index, the age, the productivity, the structure and phytosanitary state are factors with relevant contribution (Florescu 1981). This is the reason we assigned them a more important weight.

Canopy density and configuration, as well as their coverage indexes, are the features with the highest contribution rate within the analysis of the windthrow susceptibility in the Iezer Mountains.

In the Romanian Carpathians different studies showed that pure Norway spruce forests are the most sensitive to wind and snow damages. The most stable are the mixed forests with spruce (*Picea abies*) and beech (*Fagus silvatica*), but stability depends on the species percentage.

Tree canopy density and canopy coverage index are also influenced by *human activities*. Trees can be damaged around the timber harvesting areas, around roads, electric power lines and cable car lines, and this can expose the canopy to the wind action (Ichim 1976, 1990).

The age of the stands is also essential, mainly when the trees are about the same age (secondary forests). These forest patches are vulnerable to wind damages when they are usually younger than 30 year (Ichim 1990). Primary forests (natural stands) are often featured by different tree species, different age and heights, showing a high degree of stability (Ichim 1976, 1990). Such a condition is very rare in the Iezer Mountains.

Based on these statements, we established the reclassifying conditions of each data layer for our analysis. Table 4 provides a synthesis of these features.

Table 4. Reclassification conditions of digital data for the windthrow susceptibility map in the Iezer Mountains and other mountain regions in Romania.

ENDOGENOUS NATURAL FACTORS

Species within canopies		pure spruce fir forest patches (more than 70% spruce fir trees)	mixed forests with 40-60% spruce fir	mixed forests with fir and beech trees	other forest patches
	1.	68	25	5	2
	2.	66	26	5	3

Canopy age (years)		< 40	40-60	60-80; > 120	80-100	100-120
	1.	8	22	40	16	14
	2.	9	21	38	17	15

Canopy coverage index		0.8-1	0.5-0.7	< 0.5
	1.	9	64	27
	2.	10	60	30

Canopy productivity class		I	II + III	IV + V
	1.	20	72	8
	2.	24	70	6

NATURAL EXOGENOUS FACTORS - Local conditions

Slope aspect		N	NE	E	SE	S	SW	V	NW	flat
	1.	26	14	15	7	15	4	11	7	1
	2.	24	12	17	8	12	6	12	8	1

Soil depth		deep	medium	shallow
	1.	3	35	62

Soil edaphic volume		big	medium	little
	1.	1	29	70

1. Percentage (%) obtained after the statistic analysis of the windthrows occurred in Iezer Mountains starting since 1960 (1960, 1964, 1965, 1974, 1977, 1985, 2002 and 2005); 2. Value (%) collected from statistics and other research results regarding the windthrows in Romania (from different works).

The different percentages (values) in Table 4 confirm the importance of each factor in windthrow susceptibility analysis. In the reclassifying procedure in Arc GIS, we assigned the values in decreasing order to each factor, integrating with different weights the seven layers featured. All the seven resulting layers were introduced in a product and then the windthrow susceptibil-

ity layer was obtained. The final map needed a selection of the clusters corresponding to all the seven conditions fulfilled. A filtering procedure (median filter) was applied and compact layers were prepared for validation.

Results

Windthrow susceptibility map (Fig. 3.) shows a high degree of susceptibility in the lower part of the spruce zone and in the stands with younger spruce (secondary) forests within the mixed forest zones (beech/spruce/fir trees). This is also confirmed by different authors, about mountain spruce forests in other Central European countries like the Czech Republic and Slovenia (Šamonil et al. 2009; Firm et al. 2009; Svoboda et al. 2010). Other researches from Romania (Ichim 1990), stated that low susceptibility to windthrow characterizes the mixed forests with a low contribution of spruce.

The lowest degree of susceptibility corresponds to the primary forests because they preserve natural heterogeneity for a relatively long time (Lörz et al. 2010; Svoboda and Pouska 2008; Winter et al. 2010). They occur rarely in the Iezer Mountains and even in the Romanian Carpathians.

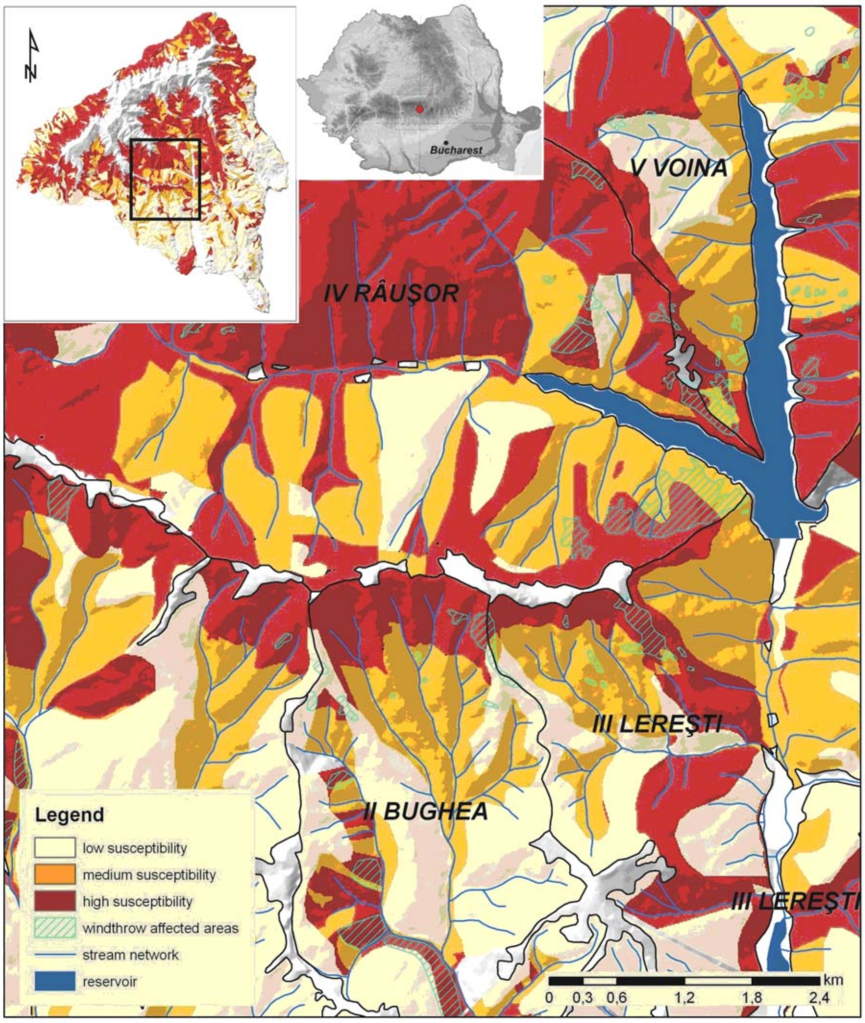

Fig. 3 Detail from the windthrow susceptibility map of the Iezer Mountains (Southern Carpathians) – the Rausor Valley. The selected area shows the situation from five different forestry productive units (UP IV Rausor). White areas are deforested lands (pastures). There can be noticed the correlation between high and medium windthrow susceptibility areas and the existing windthrow affected areas (July 2005, data from digital ortophotos, validated through field check, 2006).

Another result is the confirmation of the role of soil features. The Southern Iezer Mountains and the Magura Peak, an isolated outlier in crystalline rocks, are confronted with intensive soil erosion. This is a confirmation of the previous deforestation of these slopes. This is also documented by the old maps like the Austrian Specht Map of Wallachia, developed in 1796. According to the FAO World Reference Soil System, these soils are Leptic and Dystric Cambisols indicating a long duration of erosive episodes. They show low depth and low edaphic volume but a good drainage condition. About 50 years ago, this mountain

outlier was reforested with Norway spruce (*Picea abies*) on more than 70% of its surface. The site conditions were not the best for this type of canopy (an average annual temperature of 7.5˚C and low rainfall volumes – 770 mm). As an effect of this anthropogenic forest recovery, the canopies are highly vulnerable to windthrows and the forest disaster that occurred in the summer of 2005 (July 19) confirmed this situation (Fig. 4).

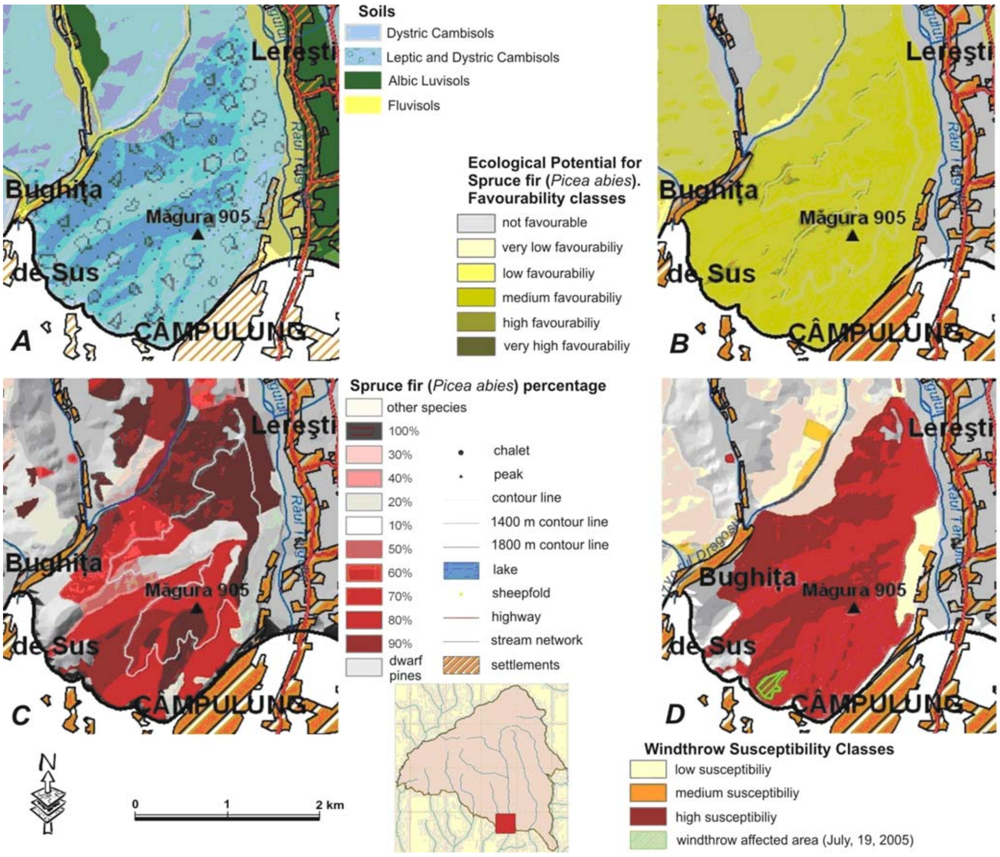

Fig. 4. Detailed maps from the Southern Iezer Mountains - Magura Mountain area (905 m a.s.l.). The maps allow the correlation between soil cover – *a* (shallow and rich in coarse materials), the Norway spruce favorability areas – *b*, the Norway spruce secondary forest – *c* (outside the coniferous zone), the windthrow occurrence areas (July 19, 2005) and the windthrow susceptibility areas – *d*.

Although the analysis does not include directly wind related spatial data, we can confirm that some of the most susceptible areas were the forest patches with recent windthrow events. A relevant example is the windthrow in Magura Mountain (905 m), close to the town of Campulung which put down about 5 hectares of spruce forest in only 20 minutes as an effect of a stormy wind blowing from west and southwest (ca. 36 m/s). The volume of fallen wood was about 5800 m^3. The forest was approximately 70 years old and belonged to the second class of productivity. Trees were uprooted in a very short time (22:00 – 22:20) and this confirmed the key role of the soil data layer within the analysis. A similar situation is confirmed by the windthrows in the Rausor catchment, were beech trees started to be affected, although the literature considers that the spruce stands are the most vulnerable to windthrows (Šamonil et al. 2009).

Our analysis also confirmed the existence of other highly susceptible areas to windthrows within the Iezer Mountains. An example is the Rausor catchment, close to the dam on the Rau Targului stream. This area has undergone extensive forest restoration works since 1935. Decades before, almost all the catchment was deforested because of its high degree of accessibility (roads, paths, forestry railroad on Raul Targului valley).

The validation of the GIS analysis was done through the comparison of the resulting clusters with the windthrow areas occurring in the Iezer Mountains between 1960 and 2005. The areas affected were mapped using the digital color ortophotos from July 2005, and aerial photos taken during the 1965, 1972 and 1980 flights. The comparison was completed with field photos (2001 to 2009) and historical photos from different private archives.

The main result of the validation process was that more than 92% of the total windthrow affected area in the Iezer Mountains superposes on the high susceptibility category areas. If we consider only the windthrow affected areas between 1960 and 2004 (lower than 65% from the total affected surface), we may conclude that 98% of the windthrow affected areas correspond to the high susceptibility class. The remaining 2% fall into the medium susceptibility class (Table 5).

Table 5. Surfaces of windthrow affected areas in the Iezer Mountains starting since 1960 and their frequencies in relationship with the susceptibility degrees for this phenomenon.

Susceptibility degree	Windthrow affected surfaces after 1960 (ha)	Frequency of windthrow (%)
low	31.1	2.9
medium	48.6	4.6
high	976.4	92.5
	1056.10	100.0

Discussion

Windthrow susceptibility mapping is a difficult task in terms of data acquisition and data quality. The availability of high quality digital data is limited in Romania. The application took a lot of time in terms of database building process.

Windthrow susceptibility modeling in the Iezer Mountains is not complete yet. Next step should focus on integration with the forestry data, soil cover data but also weather data related to the wind, as the factor that has a triggering role.

The study area has no weather station and weather data available. The nearest stations are situated as far as 10 to 40 km, in different topographic conditions. Thus, Campulung weather station is situated within a depression, at the foot of the mountains; Fundata lies in the middle of the Bran-Rucar Corridor, on a sheltered ridge belonging to the middle mountain area; and Omu is on the highest peak of the Bucegi Mountains (2,505 m), in the alpine grasslands zone.

Wind speed and direction measurements provided by the weather stations are not fully suitable to the windthrow analysis. Wind speed is recorded every 30 min all day long while the realistic wind speed can increase up to 35 m/s for only few minutes, often between two consecutive records. This situation featured the biggest windthrow in Magura Mountain on July 19, 2005 as it was documented at Campulung weather station, situated at 681 m a.s.l., 1.5 km Southern from the windthrow area, within the Campulung Depression.

Some expeditionary measurements can be useful in order to obtain relevant data about wind direction/frequency, wind speed/frequency as well as the extreme values. These data can be modeled in digital form by choosing the most suitable interpolation method and then reclassified in the framework of a new GIS analysis (Kemp 2008).

Forestry and slope aspect data can be considered an indirect integration of wind related data. Forest stand types and their attributes as well as the slope aspect can be an expression of the adaptation of the forest in relationship with the aeolian factor.

The windthrow susceptibility map obtained is a mirror of the forestry policies applied within our mountains. The National Program for Forestry Fund Conservation and Development (1976–2010) made possible the afforestation of large areas with spruce outside its ecological rank (zone). This explains the discontinuity of the areas prone to windthrow. Deciduous and stable stands were largely replaced by coniferous (spruce) stands at any altitude and slope aspect and on poor soil conditions.

Conclusions

Iezer Mountains might serve as a representative sample for the Romanian Carpathian forests. Most of these stands are of about 50 year old, with weak stability against the natural damaging factors. They are usually exposed to windthrows.

The presented application of GIS can bring to forestry specialists valuable data for further management. First of all it is possible to correlate the windthrow susceptible areas with the forest patches where the local (site) conditions were changed by the anthropogenic forest recovery with species other than natural.

The other correlation can be made easily between timber harvesting sites and susceptibility clusters on the map. It is important to observe that forest ecosystem is increasingly exposed to wind, snow, diseases and other negative factors when its features are different from its natural or primary structure. The loss of timber within the mountain forest can be controlled, after the high volumes of damages of the last 50 years (Giurgiu 1995). A GIS application is an easy to use tool in forest management decision development. The approach can follow the susceptibility probabilistic modeling (Zeng et al. 2009) or the building of forest development scenarios (Zeng et al. 2007). Forest is a system that can be modeled so that to be better analyzed and managed. Forest biodiversity should be increasingly considered within the GIS analysis, because this is the source of stability within the ecosystem.

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